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Chesapeake Research Consortium, Incorporated

REPORT ON THE EFFECTS OF TROPICAL STORM AGNES ON THE CHESAPEAKE BAY ESTUARINE SYSTEM

JUNE. 1974

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CRC

The Johns Hopkins University
University of Maryland
Smithsonian Institution
Virginia Institute of Marine Science

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THE EFFECTS OF TROPICAL STORM AGNES ON THE CHESAPEAKE BAY ESTUARINE SYSTEM

A report for the U. S. Army Corps of Engineers
Baltimore District
Contract DACW 31-73-C-0189

THE CHESAPEAKE RESEARCH CONSORTIUM, INC.

The Johns Hopkins University
Smithsonian Institution
University of Maryland
Virginia Institute of Marine Science

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Preface

During June of 1972 Tropical Storm Agnes released record amounts of rainfall on the watersheds of most of the major tributaries of Chesapeake Bay. The resulting floods, categorized as a once-in-100 to 200-year occurrence, caused perturbations of the environment in Chesapeake Bay, the nation's greatest estuary.

This report, prepared by the Chesapeake Research Consortium, Inc., under Contract No. DACW 31-73-C-0189 from the Baltimore District, U. S. Army Corps of Engineers, is an attempt to bring together an analysis of the effects of this exceptional natural event on the hydrology, geology, water quality, and biology of the Chesapeake Bay, and to consider the impact of these effects on the economy of the Tidewater Region and on public health. This is done from a perspective in time of nearly two years after the summer of the flood. An early and necessarily incomplete assessment, The Effects of Hurricane Agnes on the Environment and Organisms of Chesapeake Bay, was prepared by personnel from Chesapeake Bay Institute (CBI), Chesapeake Biological Laboratory (CBL), and Virginia Institute of Marine Science (VIMS) for the Philadelphia District, U. S. Army Corps of Engineers. Most of the scientists who contributed to the early report have conducted further analyses and have written papers forming a part of this report on the effects of Agnes. Additional contributions have been generated by other scientists most notably in the fields of biological effects and economics.

It is hoped that this analysis of the Agnes event will usefully serve government agencies and private sectors of society in their planning and evaluation of measures to cope with and ameliorate damage from estuarine flooding. It is also hoped that from this report, the scientific and technical sector of society will gain a better understanding of the fundamental nature of the myriad and interrelated phenomena that is the Chesapeake Bay ecosystem.

The Chesapeake Research Consortium under terms of the contract, sponsored a symposium held May 6-7, 1974 at College Park, Maryland, at which some 50 papers were delivered. The symposium provided a forum for discussion of Agnes' effects by all members of the Chesapeake Bay scientific, technical, and managerial community. Although the papers presented at the symposium are included among the Technical Reports of this document either in their entirety or as abstracts, CRC proposes to sponsor their submission for publication in the open scientific literature as a symposium volume in order to increase their availability to the scientific and technical community. Presumably much of what was learned about Chesapeake Bay will be applicable to other estuarine ecosystems elsewhere in the world.

This report represents an attempt to bring together all data no matter how fragmentary relating to the topic. The authors are to be congratulated for the generally high quality of their work. Those who might question, in parts of the purse, the fineness of the silk must keep in mind the nature of the sow's ears from which it was spun. This is not to disparage, but only to recognize that the data were collected under circumstances which at best were less than ideal. When the flood waters surged into the Bay there was no time for painstaking experimental design. There were not enough instruments to take as many measurements as the investigators would have desired. There were not enough containers to obtain the needed samples nor enough reagents to analyze them. There were not enough technicians and clerks to collect and tabulate the data. While the days seemed far too short to accomplish the job at hand, they undoubtedly seemed far too long to the beleaguered field parties, vessel crews, laboratory technicians, and scientists who worked double shifts regularly and, literally, around the clock on many occasions. To these dedicated men and women whose quality of performance and perseverance under trying circumstances was so outstanding, society owes an especial debt of gratitude.

It is worthy of note that CBI, CBL, and VIMS, the three major laboratories oriented toward research on Chesapeake Bay, undertook extensive data gathering programs requiring sizable commitments of personnel and equipment without assurance that financial support would be provided. The emergency existed and the scientists recognized both an obligation to assist in ameliorating the destructive effects and a rare scientific opportunity to better understand the ecosystem. They proceeded to organize a coordinated program in the hope that financial arrangements could be worked out later. Fortunately, their hopes proved well founded. Financial and logistic assistance was provided by a large number of agencies which recognized the seriousness and uniqueness of the Agnes phenomenon. A list of those who aided is appended. Their support is gratefully acknowledged.

This document consists of two parts: a series of detailed Technical Reports preceded by a Summary Report which is an attempt to describe succinctly those Agnes effects of significance to management. Authorship of each of the Technical Reports is indicated. To these scientists, the editors extend thanks and commendations for their painstaking work.

Several members of the staff of the Baltimore District, U. S. Army Corps of Engineers, worked with the editors on this contract. We gratefully acknowledge the helpful assistance of Mr. Noel E. Beegle, Chief, Study Coordination and Evaluation Section, who served as Study Manager, Dr. James H. McKay, Chief, Technical Studies and Data Development Section, and Mr. Alfred E. Robinson, Jr., Chief of the Chesapeake Bay Study Group.

Also the editors are grateful to Beverly L. Laird, Alice Lee Tillage, Claudia B. Walthall, and Melissa A. Forrest for their efficiency, patience and perseverance in redacting the manuscript.

The Summary Report was compiled from summaries of each section prepared by the section editors. I fear that it is too much to hope that in my attempts to distill the voluminous, detailed and well prepared papers and section summaries, I have not distorted meanings, excluded useful information or overextended conclusions. For this I extend my apologies. The authors and section editors are responsible for the generally high quality of the Technical Reports. For whatever shortcomings and inaccuracies that exist in the Summary Report, I am to blame.

Jackson Davis
Project Coordinator

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THE EFFECTS OF TROPICAL STORM AGNES ON THE CHESAPEAKE BAY ESTUARINE SYSTEM

SUMMARY REPORT

Hydrological Effects

The Storm and Resulting Flood

The Tropical Storm named Agnes started on the Yucatan Peninsula as a tropical disturbance on 14 June 1972. Within four days it developed to hurricane intensity in the Gulf of Mexico northwest of Cuba. The path of Agnes from tropical depression through hurricane and finally to extratropical stage is shown in figure 1. While Agnes was in her infancy on the Yucatan Peninsula, a weak cold front moved through the region which serves as the watershed to Chesapeake Bay and its tributary rivers. This cold front was responsible for rainfall in the Chesapeake watershed in amounts from one to three inches with isolated stations in Maryland reporting up to six inches. This rainfall, although not exceptionally strong for the region, served to further saturate a watershed which was already suffering from an unusually wet winter and spring.

Rains directly attributable to Agnes reached the watershed on 21 June and lasted through 23 June. Figure 2, a grouping of radar echo pictures shows the movement of precipitation echoes through the watershed from southwest to northeast on 21 and 22 June. The entire watershed was subjected to measured rainfall in excess of six inches with approximately one third of the region receiving more than twelve inches of

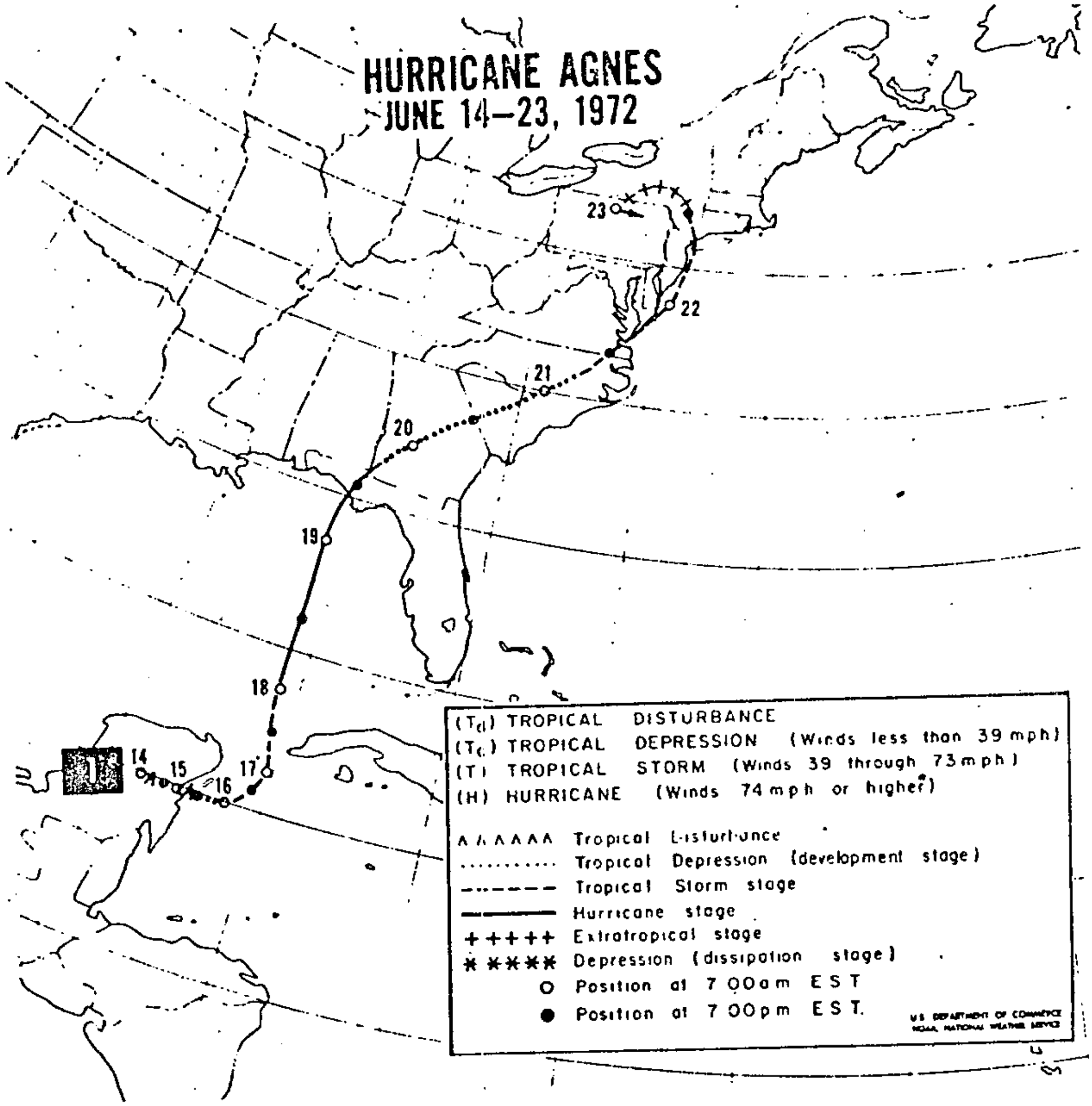
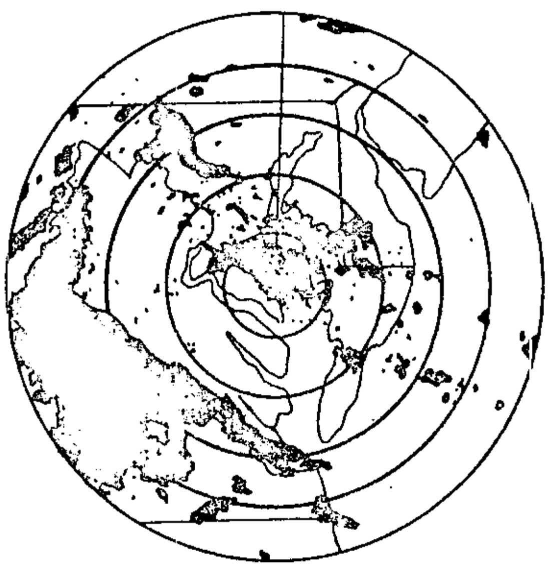
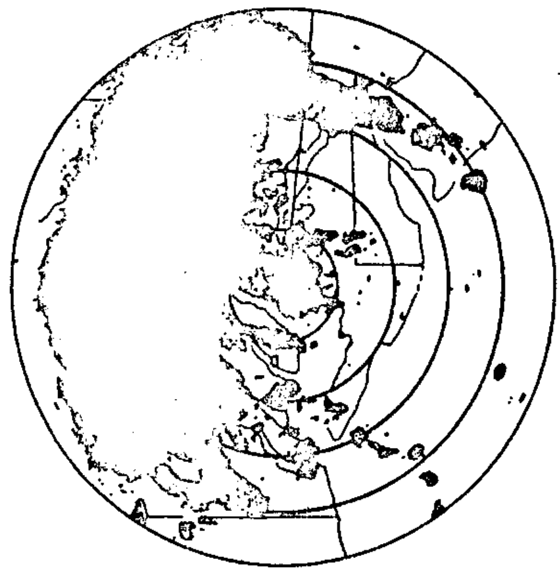


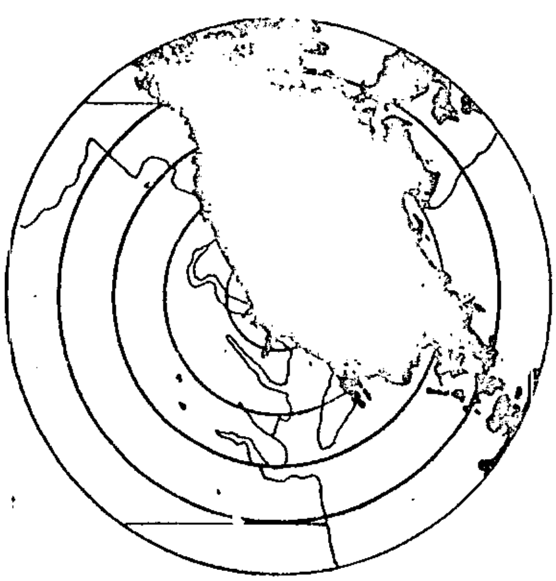
Fig. 1. Track of the center of Hurricane Agnes. Rains and winds extended out from the storm center over long distances. From DeAngelis and Hodge, 1972. Preliminary Climatic Data Report: Hurricane Agnes, June 14-23, 1972. U. S. Dept. of Commerce, NOAA, Technical Memorandum EDS NCC-1. iv + 62 p.



21 June 0709 EST



21 June 1900 EST



22 June 0700 EST

22 June 1725 EST

Figure 2. Precipitation echoes over the Chesapeake Bay watershed observed by the Patuxent weather station.

water and isolated locations recording eighteen iches in the three day period.

This deluge, on a saturated watershed, resulted in immediate flooding of the major tributaries to Chesapeake Bay. Major tributaries to Chesapeake Bay are the Susquehanna, Potomac, Rappahannock, York and James Rivers. Their relative positions are shown in figure 3. Most rivers crested at levels higher than previously recorded. Table 1 lists average flows for the month of June as well as average daily flows and instantaneous peak discharges for major tributaries to Chesapeake Bay for the period 20 to 27 June 1972. These flows were measured (or estimated) at the furthest downstream gauging station in each river (usually just upstream of the region of tidal influence).

From 21 to 30 June 1972, the Susquehanna River, usually responsible for 61% of the fresh water contributed to Chesapeake Bay in June, had flows averaging 15.5 times greater than normal. This river accounted for 64% of the fresh inflow to the Bay for the ten-day period. This volume of water from the major tributary resulted in a 30 nautical mile translation of fresh water down the Bay (based on the movement of the 5 ppt isohaline). Had Chesapeake Bay been a reservoir (i.e. if a dam existed between the Virginia Capes), the water level in the Bay and all its tidal tributaries would have been increased by approximately two feet from the ten-day Agnes-induced flooding of all major tributaries to the Bay.

The relative effect of Agnes flooding on each major tributary becomes apparent when flows are normalized to average June flows. Flows are normalized by dividing each daily flow by the normal

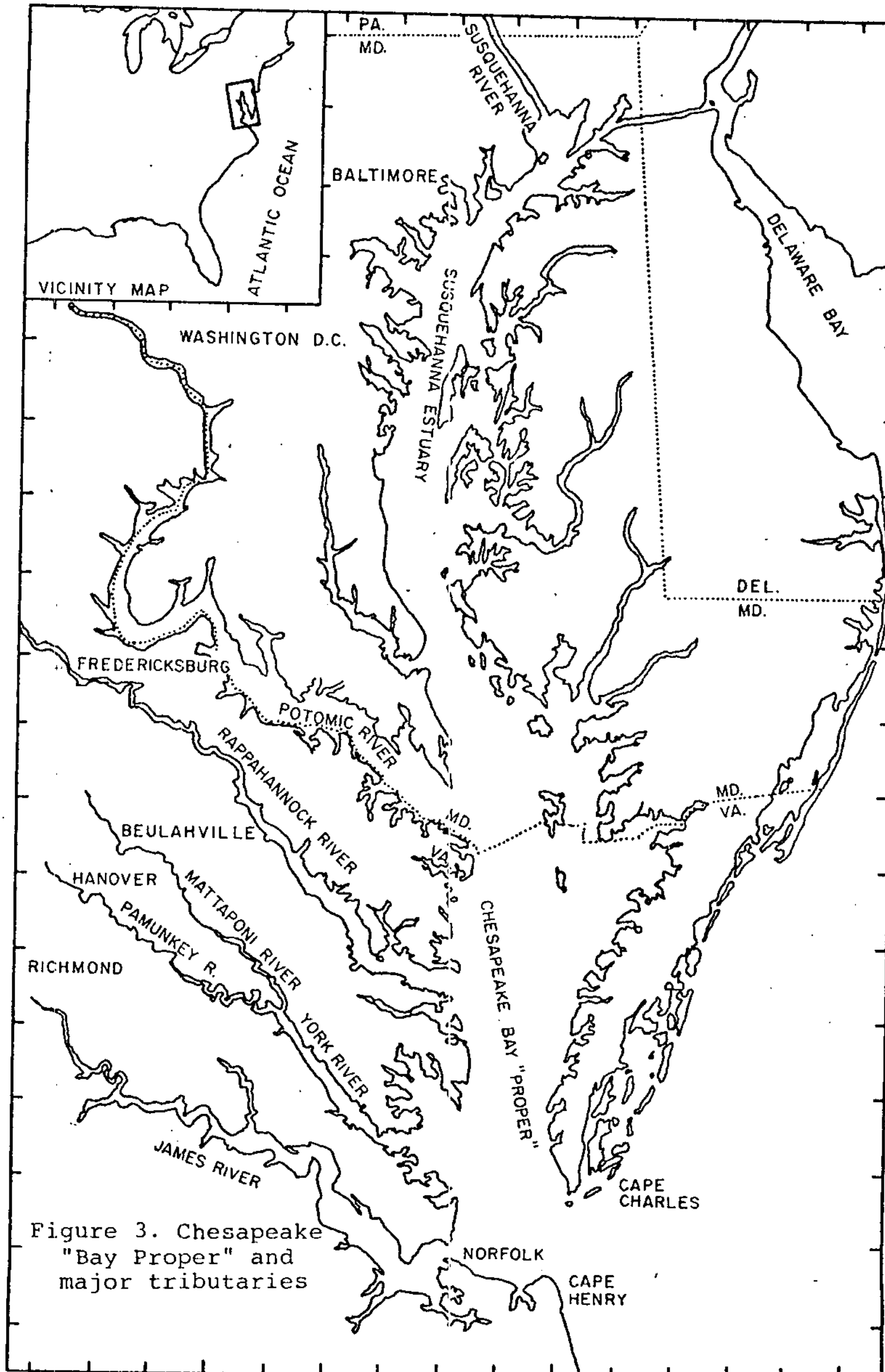


Figure 3. Chesapeake "Bay Proper" and major tributaries

Table 1. Gauged flows for major tributaries to Chesapeake Bay during flooding from Tropical Storm Agnes. (Numbers in parenthesis indicate instantaneous peak flows).

River (Gauging Station)	Drainage Area Above Fall Line (Sq. Mi.)[3]	Normal Av. June Flows (cfs)[1]	Average daily flows (cfs)[1] for June 1972							
			20	21	22	23	24	25	26	27
Susquehanna (Conowingo, Md.)	27,089	35,000*	54,200	50,400	445,000	1,040,000	1,120,000 (1,130,000)	1,010,000	696,000	418,000
Potomac (Washington, D.C.)	11,560	8,020	7,160	12,000	172,000	268,000	334,000 (359,000)	200,000	79,800	35,600
Rappahannock (Fredericksburg, Va.)	1,599	1,240	1,090	6,380	84,200 (107,000)	44,500	18,200	7,410	5,100	4,600
York (Beulahville, Va.) Hanover, Va.)	1,691	859	1,793	3,091	10,460	30,730 (35,630)[2]	34,300	32,500 (33,200)[2]	28,700	21,480
James (Richmond, Va.)	6,757	4,650	9,220	14,300	136,000	296,000 (313,000)	210,000	88,700	28,700	19,900

Note: 1- cfs = cubic feet per second.

2- The York River has two major tributaries where furthest downstream gauging stations are located: On the Mattaponi River, the gauging station at Beulahville, Va. recorded a peak instantaneous flow of 16,900 cfs on 25 June; on the Pamunkey River the gauging station near Hanover, Va. recorded a peak instantaneous flow of 29,900 cfs on 23 June. These instantaneous peak flows, combined with average daily flows in the associated York tributary gave combined peak flows into the York system as shown.

3- Drainage area statistics from Seitz, R. C. Drainage Area Statistics for Chesapeake Bay Fresh-Water Drainage Basin. CBI Special Report 19, Feb. 1971.

*- Based on USGS info available in this office this value appears high by $\pm$ 8000 cfs.

daily June flow for each river. Figure 4 shows daily normalized flows for the major tributaries to the Bay during the period 20 June - 5 July 1972. Normalized peak instantaneous flows are also shown. From this figure, it is apparent that two forms of flooding occurred: (1) an abrupt flow increase in excess of 60 times normal, followed by an equally abrupt decrease in flow back to approximately six times normal as is illustrated by the James and Rappahannock Rivers, and (2) a somewhat slower increase in flow to 30 or 40 times normal followed by a decrease in flow which took twice as long as the increase as is illustrated by the Susquehanna and York Rivers. The normalized record for the Potomac River falls somewhere between these two. Table 2 illustrates that for normalized flows, flooding in the York River was most severe. When actual volumes of water are considered, however, flooding in the York was less severe because of the low flows usually experienced in June (see Table 1). Additionally, peak flooding in the Mattaponi and Pamunkey Rivers, the major tributaries to the York, occurred at different times (see Table 1). Of all major tributaries to the Bay, the York was least affected by Agnes-induced flooding.

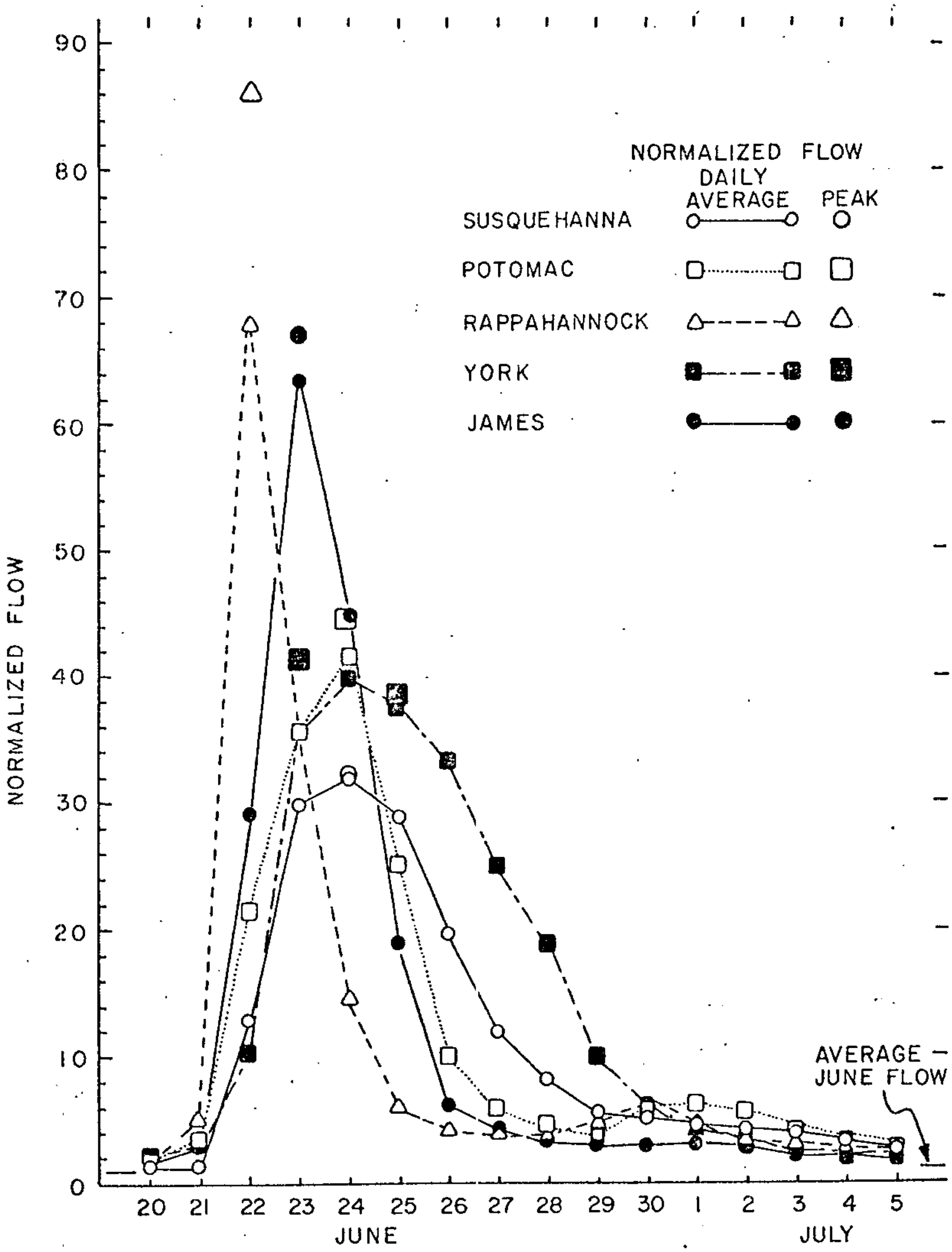


Figure 4. Normalized daily flows for major tributaries to Chesapeake Bay during flooding from Tropical Storm Agnes, June-July 1972.

Table 2. Normalized flows for major tributaries to Chesapeake Bay for various periods of flooding due to Tropical Storm Agnes.

River	Normalized Flows* (1972) 7 days 21 to 27 June	10 days 21 to 30 June	15 days 21 June to 5 July
Susquehanna	19.5	15.5	11.6
Potomac	19.7	15.4	9.2
Rappahannock	19.6	15.2	11.3
York	25.3	21.2	15.2
James	24.4	18.0	12.8
Total for all rivers shown	22.2	17.3	12.4

$$* \text{ Normalized flow} = \frac{\text{average flow per period}}{\text{normal average June flow}}$$

Effects of Flood Waters on the Salinity Distribution in Chesapeake Bay, Its Major Tributaries and Contiguous Continental Shelf

Prior to the Agnes flood, Chesapeake Bay was in an unusual hydrologic condition. Whereas water temperature was similar to that expected in late spring or early summer, the salinity distribution was most akin to that expected in mid-spring owing to greater than average flows during the preceding winter and spring. Hence salinity was depressed more than in June of a year of more normal rainfall.

Chesapeake Bay and each of its major tributaries showed similar reactions to Agnes flooding. Generally, four stages were observed (Fig. 5).

1) Initially, flood waters forced surface salinities downstream several miles while bottom salinities remained somewhat constant, producing highly stratified estuaries. Distance and duration of the displacement were dependent on the dimensions of each particular basin and the magnitude of flooding within that basin.

2) The second stage of reaction to the flood was similar to the first but operated on bottom rather than surface waters shifting them downstream. This resulted in vertically homogeneous estuaries of very low salinity.

3) The third stage was essentially a reaction to the first two and is presumed to be the result of gravitational circulation. During this stage, there was a net transport of salt up the estuaries. This transport started in the lower layers, eventually acted on surface water and, particularly in the lower layers, moved salt water upstream substantially beyond the pre-Agnes position.

4) The final stage was vertical mixing between surface and bottom water which resulted in salinity structure similar to that expected during a "normal" summer. This final stage of the reaction to Agnes-induced flooding was generally underway, for the Chesapeake Bay system, by the end of September, approximately 100 days after the flood waters crested at the fall line.

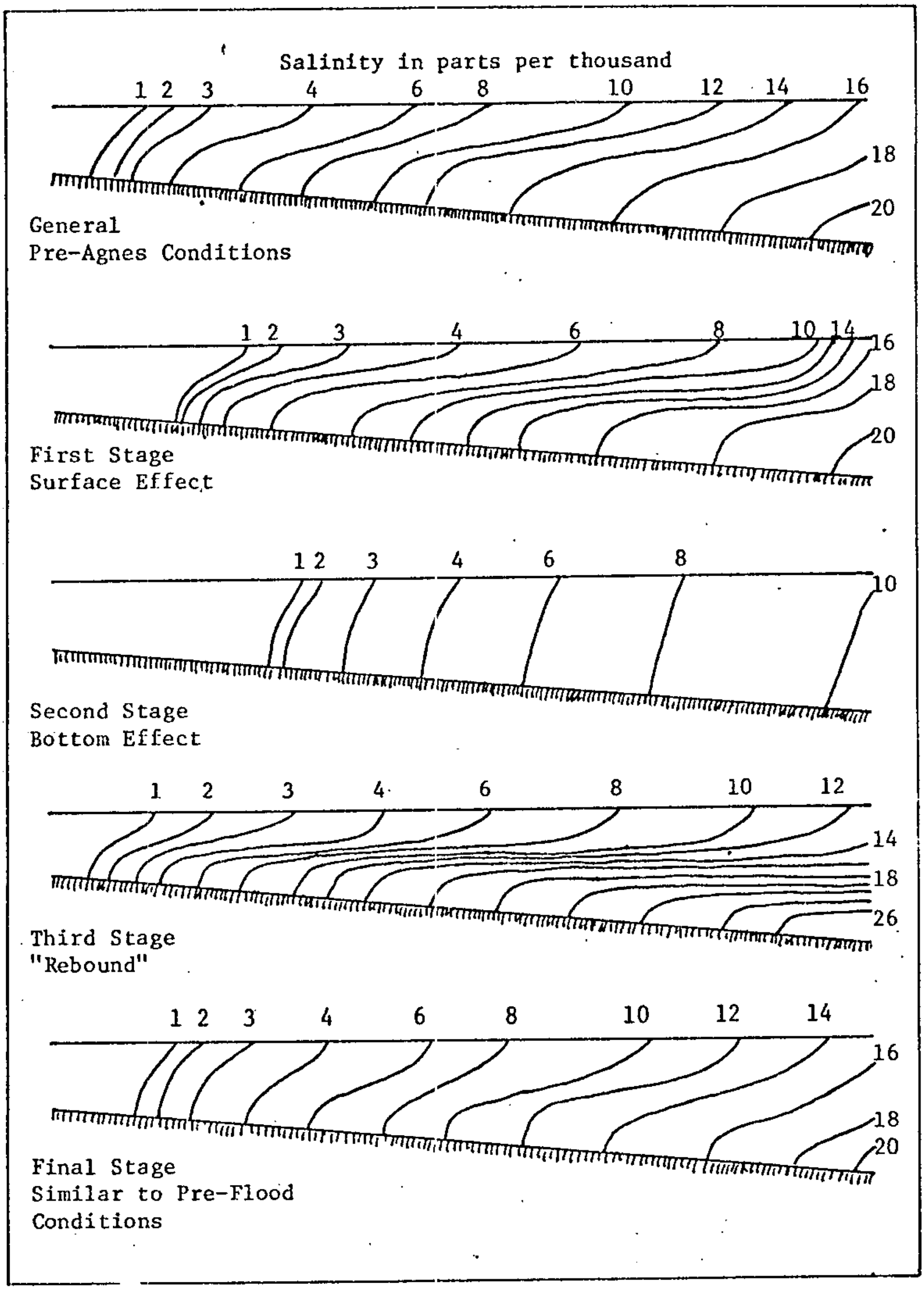


Figure 5. Schematic representation of reaction to Agnes flooding.

Chesapeake Bay and its major tributaries can be segmented into two categories: The "Bay Proper" and the tidal-estuarine portions of the major tributaries as shown in figure 3. If we consider the northern portion of the Bay (north of the Potomac River) as the estuarine portion of the Susquehanna River, then the southern portion of the Bay is the "Bay Proper". The generalized sequence of events described above was evident to some extent throughout the estuarine system but was most pronounced in the James and York rivers and the "Bay Proper". The remaining major tributaries showed the first two (downstream directed) stages but were subjected to bay-tributary interactions dur- the third (upstream directed) stage. At the time the Potomac and Rappahannock rivers went through the third stage, the up-bay encroachment of high salinity water had not reached their mouths. The result was an upstream movement of slightly salty water into these rivers from the northernmost portion of the "Bay Proper". This situation did not occur in the James and York rivers because of their proximity to the ocean.

The lower Bay was subjected to a cascade of flooding from the major Virginia tributaries as well as the initial flooding from the Susquehanna. The early effect is shown in figure 6 which illustrates surface salinities for the period 29 June to 3 July. Flood waters from the Susquehanna and Potomac coursed down the center of the Bay bypassing pockets of higher salinity water in smaller

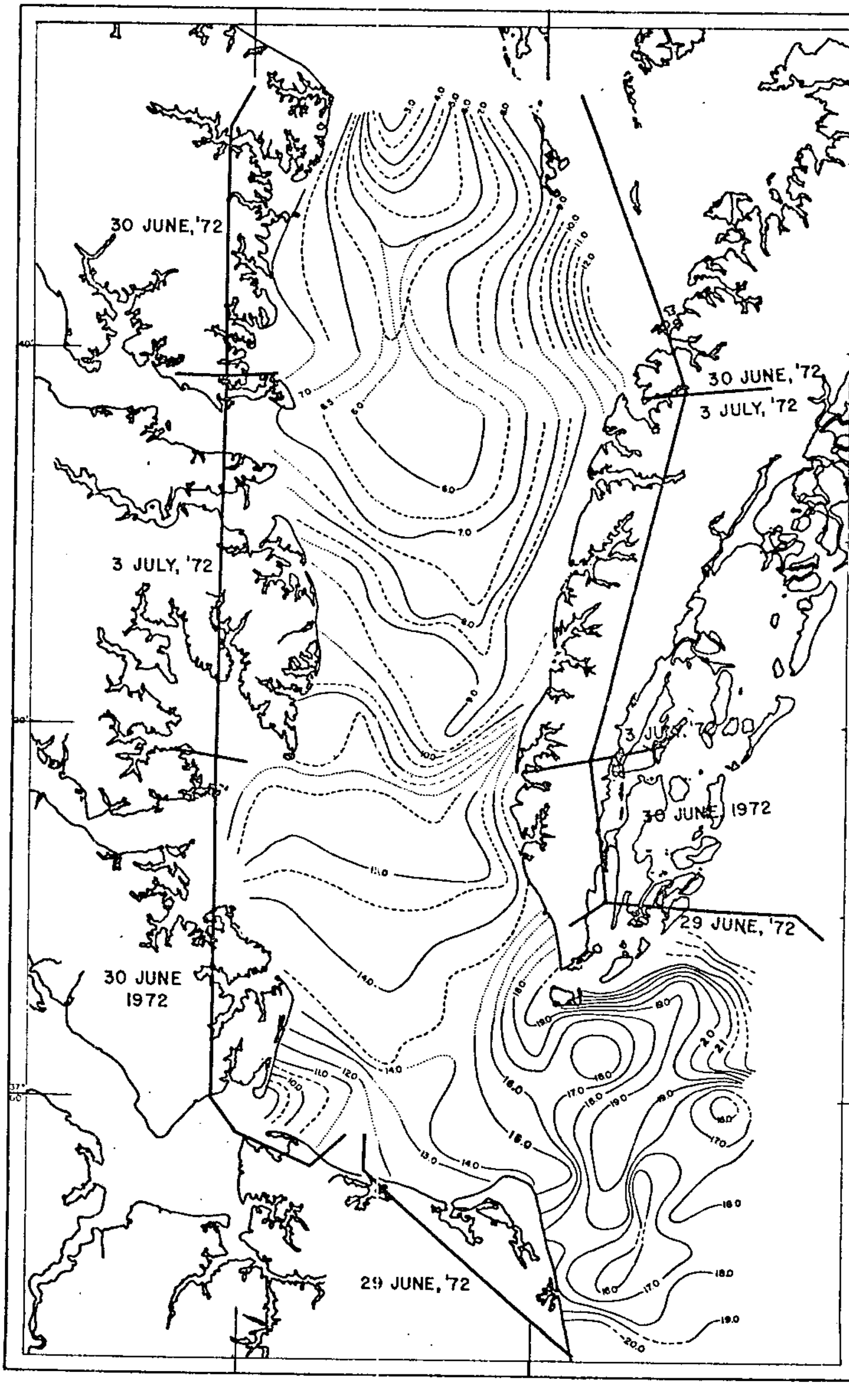


Fig. 6. Surface salinities for lower Chesapeake Bay during the period 29 June - 3 July 1972.

tributaries on either side. Approximately seven days later (Fig. 7) large patches of freshened water from the Potomac and Rappahannock had progressed some distance downstream from their mouths.

Analyses of over 120 sampling runs conducted on the James, York, and Rappahannock rivers to measure temperature, salinity, dissolved oxygen and suspended sediments indicate that these tributaries to the Bay were subjected to internal seiches (essentially resonating waves within a particular basin) which were generated by the flood shock. These internal oscillations with periods from four to fifteen days helped to mix these estuaries vertically.

Analyses of current and tide data in the James River indicate the following:

1. Rise in water level was slight indeed in the tidal rivers in comparison with that experienced above the Fall Line. Water level elevations of approximately 6 feet above predicted tidal levels occurred in the upper portions of the tidal rivers, but no change was discernible at the mouths. Passage of the storm's low pressure center caused an increase in water level of a few inches.
2. The normal tidal current pattern was disrupted, there being a continuously ebbing current for several days as far downstream as the zone of transition from fresh to salt water. Downstream of that zone, surface waters ebbed continuously for three days, but lower layers showed normal ebb and flood current oscillations.

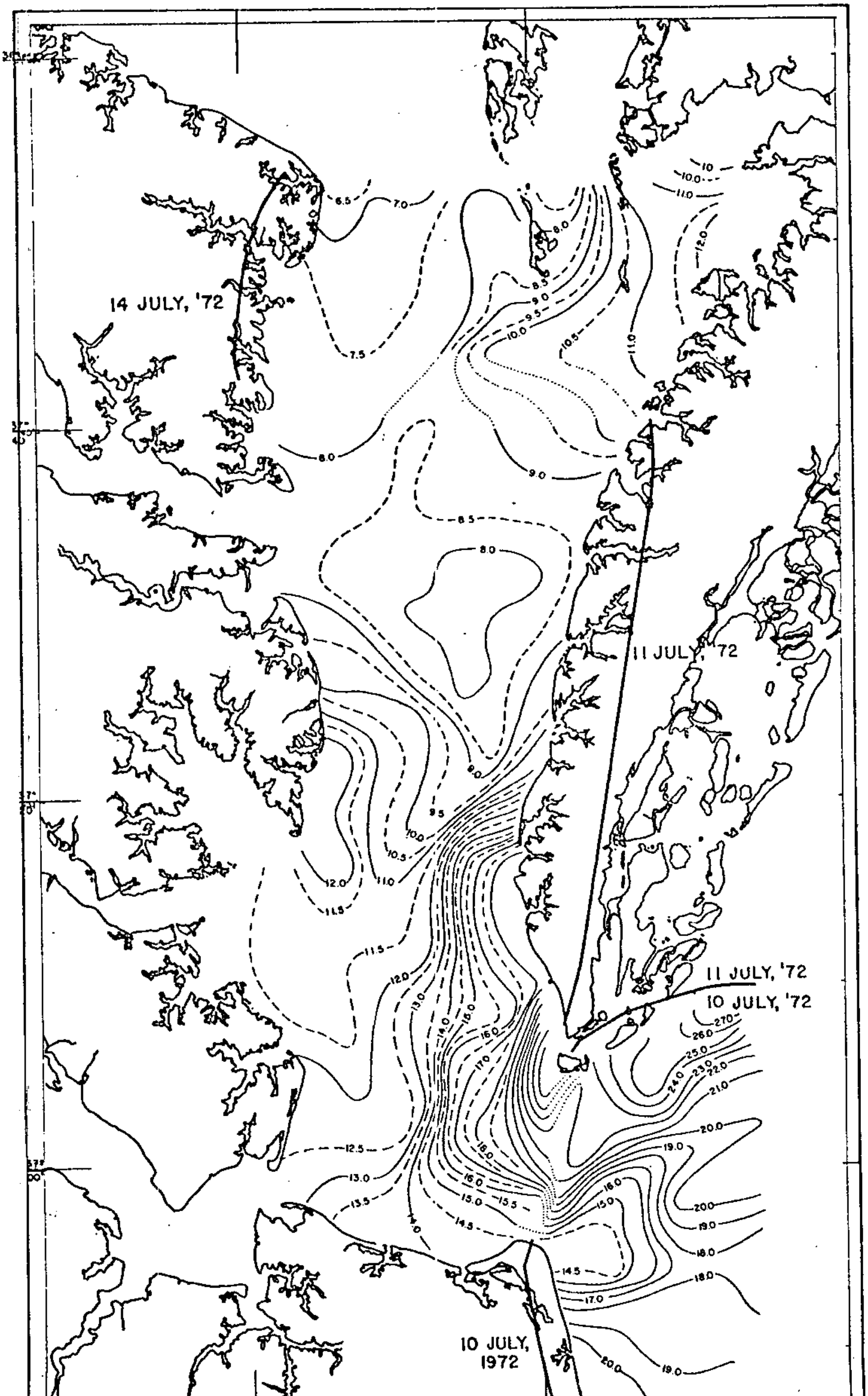


Fig. 7. Surface salinities of lower Chesapeake Bay during the period 10-14 July 1972.

Movement of Agnes flood waters onto the continental shelf was traced with one cruise by the Chesapeake Bay Institute and five cruises by the Virginia Institute of Marine Science. Flood waters leaving the mouth of the Bay moved southward along the coast. Freshened water remained in the upper 10 meters (33 feet) of the water column and was broken into large patches by tidal motion at the Bay mouth. Mixing of the patches of fresh water with ocean water was most prominent on their eastern boundaries, there being little vertical or north-south mixing.

Effects of Agnes Flooding on Smaller Tributaries to Chesapeake Bay

In general, small tributaries to the Bay became reverse estuaries after the passage of the Agnes flood. Their normal source of salt water, the Bay, became substantially fresher than these small rivers. Fresh water moved upstream from the mouth in the surface layers and saltier water moved from the upstream reaches toward the mouth in the lower layers. These conditions persisted for varying lengths of time depending on the recovery of adjacent portions of the Bay. Seiche conditions similar to those observed in the large tributaries were evident as surface phenomena and were attributed to wind set-up rather than freshwater flooding.

Geological Effects

Tropical Storm Agnes clearly constituted a major event in the history of the Chesapeake Bay estuary. The Chesapeake

Bay, like other estuaries, is an ephemeral feature on a geological time scale. The sediments that are rapidly filling the Bay basin will gradually expel the intruding sea that formed the estuary and convert the Bay back into a river valley system. If sea level remains relatively constant, this process will take at most a few tens of thousands of years to complete. If sea level rises, the life of the estuary will be prolonged. If sea level falls, its lifetime will be shortened. The rate of filling of the basin is generally greatest in the upper reaches of the estuaries because of the proximity to the fluvial sources, and because of the dynamic processes in the estuary. The sedimentological processes that characterize the Bay under "normal" or "average" conditions have been described by a number of investigators, but there was, until Agnes, a dearth of observations of the effects of episodic events such as floods and hurricanes on the geological history of the Bay. Sampling during episodes is often difficult and the infrequency of such events makes the likelihood of fortuitous observations very small. Tropical Storm Agnes presented scientists with an unusual opportunity to document the impact of a major flood on the Chesapeake Bay estuarine system. Since there was little wind associated with Agnes by the time she reached the Bay, sampling in the Bay was not hampered by high seas. The heavy rains stripped large quantities of soil from throughout much of the drainage basin, and the swollen streams and rivers produced significant bank erosion in upland areas. Much of the fine grained sediment was carried into the Chesapeake Bay estuarine system. The primary mode of sediment transport both into and within the Bay was as suspended load.

In a ten-day period (21-30 June 1972) the Susquehanna River--the long-term supplier of approximately half of the total fresh water input to the Chesapeake Bay estuarine system--discharged more sediment than during the preceding ten years, and probably during the previous quarter of a century, and perhaps even longer. The suspended sediment discharge at Conowingo during this ten day period was estimated to be more than 31 million metric tons, compared to an average annual input during "normal" years of only one-half to one million metric tons. The Agnes sediment was very similar in texture to that normally discharged. It was primarily silt and clay, but a significant amount of fine sand was also discharged.

Sediment discharges of the other major western shore tributaries were also anomalously high, but there is a paucity of suspended sediment data for these tributaries, except the Rappahannock River. The Rappahannock probably discharged more than a million metric tons of sediment during Agnes. Since the Eastern Shore (the Delmarva Peninsula) did not receive the heavy rainfall associated with Agnes, increases in the water and sediment discharges of the Eastern Shore tributaries were relatively small.

The large influxes of suspended sediment by the major tributaries raised concentrations of suspended sediment throughout much of the Chesapeake Bay estuarine system to levels higher than any previously reported. In the upper Bay concentrations exceeded 1000 mg/l in the surface waters for a few days, and in the upper reaches of the Potomac, Rappahannock, James and other major estuaries, concentrations of several hundred mg/l were observed. Normally concentrations are near 10 mg/l in surface waters. In the upper "Bay Proper", and in the upper reaches of the tributaries, there were marked downstream gradients of the concentration of suspended sediment during the period of peak flow. The downstream decreases were produced primarily by the settling out of sediment, dilution of river-water by Bay water being a minor factor. The bulk of the sediment discharged by the Susquehanna, probably more than 75% of it, was deposited in the upper reaches of the Bay--upstream from Tolchester. The bulk of the sediment discharge by the other rivers was trapped in a similar fashion in the upper reaches of the estuaries of those rivers, and relatively little reached the "Bay Proper". For example, 99% of the sediment discharged by the Rappahannock River was deposited within the Rappahannock estuary, upstream from the juncture of that tributary with the main body of the Bay.

Since the Susquehanna is the only river that discharges directly into the main body of the Bay without an intervening estuary, its effect on the distribution of suspended sediment in the "Bay Proper" was most apparent. This input, combined with the suspended sediment that escaped the tributary estuaries sent concentrations of suspended sediment in the middle and lower reaches of the Bay during late June and July to levels two-to-threefold higher than "normal" for that time of year. The outflow from the Bay could be traced as a low salinity, turbid band of water that turned south after leaving the Virginia Capes, and flowed along the Carolina coast. The concentrations of suspended sediment in this nearshore band were higher than any previously reported for this segment of the shelf.

As riverflows subsided, the normal two-layered estuarine circulation patterns were re-established in the upper Bay, and in the upper reaches of the tributary estuaries. As salt water was advected upstream in the lower layer there was a net upstream movement of fine sediment suspended in the lower layer. Sediment previously carried downstream and deposited by the Agnes floodwaters was resuspended by tidal currents and gradually transported back up the estuary. The routes of sediment dispersal are clear, but the rates of movement are obscure in nearly all of the Bay and its tributaries. The available data do not permit reliable estimates of sediment transport, particularly during the recovery period. Studies of the longitudinal distributions of transition metals in the bottom sediments suggest the importance of this upstream movement during the recovery period.

Sedimentation rates were greatest in the upper reaches of the Bay and its tributaries, and decreased markedly in a downstream direction. In large areas of the upper Bay between Turkey Point and Tolchester 15-25 cm of new sediment was deposited by Agnes. In the shipping channel in this same region as much as one meter of new material was deposited. According to CBI observations, farther upstream on the Susquehanna Flats approximately ten acres of new islands and several hundred acres of new inter-tidal areas were formed. In addition, there was appreciable fill in several stretches of the shipping channel that extends from Havre de Grace to the head of the Bay.

In the middle and upper Rappahannock estuary between 2 and 7.5 mm of new sediment was deposited during Agnes. This corresponds to approximately one-third the average annual accumulation of sediment in this stretch of the estuary. The depositional pattern of the Agnes sediment was indicated by the distribution of "extractable" copper in the bottom sediments before and after Agnes. The inorganic fraction of the copper content of the Rappahannock sediments increased by a factor of 2 to 3 during Agnes, but returned to "normal" levels within one year. The return to normal levels probably resulted from a combination of processes: by the upstream transport of copper-rich Agnes sediments in the lower layer, by the resuspension and seaward transport of Agnes sediments in the upper layer, by the mixing of Agnes sediments with underlying sediments by burrowing organisms, and by chemical re-equilibrium.

Since there was little wind associated with Agnes when she reached the Bay, seas were not unusually high and evidence of abnormal shore erosion by wind waves was equivocal. Significant erosion did occur along some stretches of the shoreline where relief is high and banks are comprised of normally erosion resistant clayey sediments. Banks comprised of apparently more easily erodible, unconsolidated Pleistocene sediments suffered less erosion. Erosion was most pronounced in the non-marine Cretaceous clays of the Potomac Group and an examination of these areas revealed that the erosion was produced primarily by a combination of torrential rains, movement of groundwater, and failures (slippages) of water-saturated sediments on unstable slopes. It is likely that these processes account for much of the erosion of the margins of the Bay even during "normal" years.

Floods of the magnitude of Agnes have a recurrence interval of about 100 to 200 years; floods of lesser magnitude occur even more frequently. Comparison of sedimentological data collected during and immediately following Agnes with data collected during "average" conditions over many years indicates that episodic events probably have a much greater and more persistent impact on the sedimentary history of the Chesapeake Bay than do average conditions.

The impact of Agnes on the Bay was clearly depositional and not erosional; the erosion occurred farther upstream in the drainage basin. Some parts of the Bay aged, geologically, by more than a decade in a week. It appears unlikely however, that the sediments deposited during Agnes will be preserved in the geological record of the Bay as a discrete sedimentary layer covering large areas of the Bay and its tributaries.

The normal physical, and particularly the biological mixing processes will in many areas largely obliterate the upper and lower boundaries of this layer. In some areas however, particularly where sedimentation rates were very high, this layer will be preserved. Examination of long cores from the upper Bay have revealed other sedimentary layers very similar in character to the Agnes layer. Were these deposited by earlier floods? Perhaps.

Water Quality Effects

Several investigators studied the effects of Tropical Storm Agnes on the nutrient budgets of the Chesapeake Bay as well as smaller sub-estuaries. Considering the importance of experimental design in any field experiment and the fact that "Agnes" allowed almost no warning or time for design, the data obtained were surprisingly informative.

The rains and resulting floods carried massive amounts of nitrogen and phosphorus compounds into the Bay. For instance, between 28 June and 30 August 1972, nearly 600 metric tons of dissolved nitrogen and 50 tons of dissolved phosphorus were delivered to the head of the Patuxent River estuary. During the flood peak the Susquehanna River delivered nearly 1500 tons of ortho-and poly-phosphate and 2500 tons of nitrate to the Bay per day. Most of the nutrients were lost from the water column before reaching the mouth of Chesapeake Bay. The nitrate concentrations, however, did show an increase in the lower bay over normal times.

A study conducted in the Rhode River, 6 miles south of Annapolis, showed that in this small subestuary, whose drainage basin lies entirely within the coastal plain, the major nutrient input was from the Bay, entering through the subestuary's mouth rather than drainage from its watershed. As was the case in the Bay, the nutrients were rapidly lost to the bottom sediments which in turn released them during the summer of 1972 resulting in intensive algal blooms.

Trace metal and pesticide budgets of the Bay changed, but not drastically. The metals cadmium, copper and zinc in oysters from the lower Bay were examined and compared with quantities present in 1971. The flood effected shifts in concentration gradients of these metals but not to an extent which caused public health hazards or toxicity to the animals.

The pesticide analyses (chlorinated hydrocarbons) showed no addition of these compounds due to Agnes and decreases of pesticide concentrations in oysters from some areas relative to before the storm were noted.

Dissolved oxygen concentrations were severely depressed in many places but not to the extent to cause large scale mortalities.

Biological Effects

The effects of Tropical Storm Agnes were generally minor and temporary to finfish, blue crabs, and hard clams.

Soft-shell clams and oysters, however, suffered heavy mortalities. Successful spawnings by the surviving soft-shell clams since Agnes led to a rapid recovery but the surviving oysters produced no significant set in 1972 and 1973. This lack of seed oysters combined with a high rate of harvest on the survivors portends a dismal future for the Chesapeake Bay oyster industry. The entire biological community was disrupted to some degree. Although effects remain discernible two years after the advent of Agnes, the Chesapeake Bay ecosystem has demonstrated great resiliency.

<u>Shellfishes</u>

No group of organisms was more strikingly influenced than the molluscs, or shellfishes. The influx of fresh water exposed extensive beds of shellfish to low salinities for periods longer than the shellfish could endure. The severity of mortality depended on the kind of shellfish involved, the duration of exposure to subminimal salinity, the temperature, and in some instances, on dissolved oxygen levels.

Oysters are active only when salinity is approximately 4 o/oo or higher. At lower salinity they neither feed nor pump water over their gills for respiration. The length of time oysters can survive salinity less than 4 o/oo depends largely on temperature. In winter oysters can survive unfavorable salinity for two to three months but in summer at temperatures of 70 to 80° F survival longer than three weeks cannot be expected. Similarly, in summer hard clams will survive salinity as low as 10 o/oo for only one to two weeks, and soft clams are killed if salinity persists below 2.5 o/oo for one to two weeks.

Oysters

Chesapeake Bay oysters suffered massive mortalities from the prolonged low salinities caused by Tropical Storm Agnes. The mortalities were greatest in the upper reaches of the estuaries and in the upper bay, and least along the eastern shore and at the lower ends of estuaries where salinities remained fairly high.

Oysters living north of the Chesapeake Bay Bridge, west of Cobb Island in the Potomac River, and in the upper ends of many of the tributaries suffered nearly 100% mortalities. Many of these oysters were already stressed from the low salinities that preceded Agnes. Heavy mortalities (greater than 25%) also occurred among oysters living along the western shore from the Bay Bridge 15 miles down bay to Herring Bay (especially among oysters living in less than 20 feet of water), in the upper Patuxent, and in the middle parts of the estuaries of the Potomac. Light mortalities occurred to oysters along the eastern shore of Maryland, and in the lower end of the Potomac River. The Maryland Department of Natural Resources estimates that more than two million bushels of market-sized oysters died on Maryland oyster bars because of Agnes.

In Virginia mortality of mature oysters on public oyster bars was as follows: James River 5%, Rappahnnock River 2%, Potomac River tributaries 50%, York River none. Grounds leased for private culture of oysters, being generally less favorably situated to withstand freshets, sustained greater mortality as follows: James River 10%, Rappahannock River 50%, Potomac River tributaries 70%, York River 2%. Economic impact of shellfish losses is considered in a subsequent section.

Somewhat surprisingly, the total harvest of oysters from Chesapeake Bay during the 1972-1973 season was excellent. Maryland oystermen, for example, landed some 3.1 million bushels--the highest total in 31 years. Landings, however, were down in the Potomac and in Virginia.

Reproduction by oysters was a disastrous failure in 1972. Spatfall, production of young oysters, approached the normal level only in the tributaries of Mobjack Bay. Elsewhere it was essentially nil with the exception of a very slight set late in the season in the James River. Abnormally low salinity during breeding season prevented successful reproduction. In 1973 spatfall was again abnormally low, especially so in the upper Bay and Potomac River. Thus few oysters have been added to replace those killed and seed for rehabilitation of decimated bars has been scarce.

Of some benefit to the shellfishing industry was the destruction of oyster drills, snails which prey on oysters. Drills are killed in three weeks or less by salinity below about 9 o/oo. The Rappahannock River and the Piankatank River were essentially freed of drills and extent of the area infested was reduced in the York River, James River and Tangier Sound. Drills are slow to repopulate an area, therefore oyster growers can expect a few years of reduced predation in those areas in which drills were killed.

Rehabilitation efforts are underway by the Maryland Department of Natural Resources, the Virginia Marine Resources Commission and the Potomac River Fisheries Commission. Hatchery-reared seed planted on a pilot scale in the Potomac River and its tributaries has shown satisfactory survival and growth. Brood stock has been moved into depleted areas. Cultch has been added both by exposing shell already on the bottom and by adding large quantities of new shell. Rehabilitation efforts have been hampered by the scarcity of seed oysters.

Even with the rehabilitation efforts, the future of the Chesapeake Bay oyster industry appears gloomy. Heavy mortalities followed by large harvests and poor recruitment indicate that harvests will drop and that recovery from Agnes will take a long time.

Soft-Shell Clams

Over 90% of the soft-shell clams died from the combined stresses of low salinity and high water temperature. The amount of productive clam bottom in Maryland, for example, decreased from about 26,600 acres three months before Agnes to only 500 acres after Agnes. Careful sampling in the Rhode and South Rivers shortly after Agnes, yielded not one live clam. Soft-shell clams were destroyed in the Rappahannock River, but survived in the York River and in Chesapeake Bay between these two rivers and also on the eastern shore of Maryland (Eastern Bay, Wye River, and Miles River), where the bay waters retained salinities greater than 4 o/oo. Fortunately, the surviving clams spawned successfully in the fall of 1972. Seed clams were found throughout the area, except in the Potomac River.

In 1973 the Maryland Department of Health and Mental Hygiene found high levels of bacteria in soft-shell clams throughout most of the waters under their jurisdiction and, therefore, closed the fishery. It is unclear if the high level of bacteria is a direct result of Agnes or if it merely occurred at the same time. The result was the complete loss of clam production for 1972 and for much of 1973.

Hard Clams

Hard clams are harvested primarily in the York River, the James River and the intervening section of Chesapeake Bay. Losses in natural populations occurred only in the York River and these were slight. However an estimated 50% of the clams transplanted from the James River to shallow bays in the York River and nearby areas died from exposure to low salinity.

Fishes

Adults and juvenile fish weathered the flood and reduced salinities well, although most moved downstream as much as 10 miles or into deeper water where the salinity approximated that of their normal habitats. Freshwater fishes also moved downstream into normally saline areas, but not so far as the marine forms. With the return of normal salinities the fishes returned to their normal habitats. Displacement of fishes disrupted both the recreational and commercial fisheries to a minor extent.

Many fish eggs and larvae were washed out of the nursery areas. But because information is lacking on the normal yearly fluctuations in spawning success, the relationship between spawning success and future adults, and many other factors, the effect these losses might have on future fish abundance is in question.

Plankton samples collected at the mouth of the James and Rappahannock rivers during the Agnes flood indicated that numerous fish larvae were being washed out of these rivers, as many as 6.5 million larvae per hour out of the Rappahannock during the peak of the flood. Many were goby and anchovy larvae, but other species, including shad and river herring were also captured. The loss of larvae from the Rappahannock and James is probably indictative of the losses from other nursery areas.

Once out of the nurseries the larvae were probably killed by unfavorable salinities and temperatures, predators, or the lack of proper food. At any rate, the loss of larvae from the nursery grounds might seriously affect the future abundance and distribution of fish in Chesapeake Bay. The effect of these losses on the fishery will first be felt in 1976 when maturing shad and river herring will return to spawn.

Blue Crabs

Effects of Tropical Storm Agnes on blue crab stocks appear to have been limited to 1) widespread and immediate but temporary downriver displacement of crabs, and 2) sporadic instances of crab deaths involving small numbers of crabs within two weeks following the storm. Crab fishing effort was measurably reduced after the storm, as some fishermen lost crab pots and others caught too few crabs to justify the cost and effort of baiting and resetting pots. Landings of hard crabs were about equal to those reported for the same months the two previous years despite the disruption of the fishery.

If Agnes affected reproduction, the impact was not great inasmuch as the 1972 year class fell within the normal range of variation.

Aquatic Plants

Perhaps, next to oysters and soft clams, the ecological group most depressed was submerged aquatic plants, especially in the Susquehanna Flats and along the western shore. Plants were sampled in August-September of 1971, '72, and '73 to determine trends in abundance, composition and distribution in the Bay, and major environmental factors, e.g., salinity and turbidity, effecting these changes.

Widgeongrass, Eurasian watermilfoil, wildcelery, naiads and macrophytic algae all decreased significantly through 1973. However, eelgrass decreased the most, 89%. For all species combined, the decrease was 67%. Only sago pondweed and horned pondweed increased during this period. The reduction in aquatic plants was due to a loss in area covered. In 1971, plants occurred on 29% of the area censused; in 1973 only 10%, was covered. No significant change in standing crop per unit area occurred. Lowered salinity and increased turbidity apparently effected this loss. Aquatic plants are an important food for waterfowl.

Jellyfish

The population of jellyfish or sea nettles had dwindled considerably in the fall of 1971 and very few were present in 1972. Flood waters further reduced the population of medusae to one-tenth or less of normal abundance. There was minor recovery of the population late in 1972 and 1974 is expected to see the return to normal numbers.

Plankton and Benthos

The plankton and the benthos are complex biological communities consisting of a myriad of kinds of organisms, many of which are minute and distinguishable only by specialists. Individual species comprising these communities were, as was the case with fishes, crabs and shellfishes, differently affected by Tropical Storm Agnes. These details are, however, left to the technical reports. Only general trends are treated in this summary.

In general the effects of the flood on benthos and plankton were greatest in the higher salinity (greater than about 15 o/oo) portion of the system. This estuarine segment, termed the polyhaline zone, is inhabited by typically marine organisms which are relatively intolerant of low salinity. Many of these were extirpated from much of their normal range. Included were many tunicates, echinoderms, molluscs, crustaceans, and algae. In contrast, organisms inhabiting the mesohaline (5-18 o/oo)and oligohaline (0.5 - 5 o/oo) zones are tolerant of a much wider range of salinity, longer periods of depressed salinity, and more rapid salinity changes. Although mortalities of species in zones of lower salinity occurred (e.g. oysters, soft clams, barnacles and hooked mussels) none of these were eradicated. The most striking faunal change in the mesohaline zone was an influx of organisms displaced from areas upstream. The fauna of oligohaline and tidal freshwater was not changed in species composition, though some individuals moved downstream to waters approximating their normal salinity range.

Phytoplankton increased rapidly, nourished by the organic material and other nutrients furnished by the flood-waters. The algal bloom continued through the fall of 1972 and in 1973 phytoplankton was denser than usual. Neither species composition nor seasonality of the blooms was the same as the normal plankton blooms. Red or mahogany algae were unusually prevalent. Some zooplankton species likewise experienced unusually large blooms at abnormal times of the year while other species were decimated.

The long-term effects of Agnes on planktonic and benthic communities in the bay cannot yet be fully assessed. Several affected community dominants have not fully recovered. Other dominant species although not immediately affected suffered delayed effects due to reproductive failures after the storm. Perturbations of the communities allowed the eruption of opportunistic species. Such reverberations to the initial perturbation of Agnes continue to the present.

With the exception of some minor impacts in the fisheries, these changes have not influenced man's day-to-day interactions with Chesapeake Bay. They were, however, of significance to those investigating the impact of man-induced changes because they gave some indication of the resilience of the natural communities and their responses to severe perturbation.

Economic Impact

Tropical Storm Agnes set records for physical and economic damage to the Eastern Seaboard. This fresh water flooding had major economic repercussions on the fisheries and the recreation industries which depend upon the Bay. Accordingly, this analysis was aimed at assessing the economic losses suffered by the commercial fisheries, the recreation industry, recreators, and determining the cost of debris removal and repair to navigation works. Concern was limited to the first round or primary effects. No attempt was made tc isolate multiplier effects; that is economic repercussions experienced by other sectors of the Maryland and Virginia economies. Total losses in current dollars in these sectors of the economy were $43 million. The impact was unevenly distributed through the economy, and geographically, being most severe in the shell-fishing, tourism, and recreation industries and less severe in other industries. The impact was greater in general on the western shore than on the eastern. Losses were both immediate and long term, especially in the shellfishery. Table 3 summarizes the economic losses from Tropical Storm Agnes.

Table 3. Total economic losses in Maryland and Virginia attributable to Tropical Storm Agnes.

ITEM	LOSS	
	Current Dollars	Constant Dollars* (1967=100)
Shellfish and Finfish Industries	33,628,200	24,848,200
Recreation Industries	7,498,700	5,984,597
Channel Dredging, and Boat and Ship Damages	1,615,000	1,288,907
TOTAL	42,741,900	32,121,704

*To convert to constant dollars the current dollar losses were divided by the appropriate consumer price index. The Survey of Current Business, U. S. Department of Commerce, Social and Economic Statistics Administration, Bureau of Economic Analysis, February 1973, Vol. 53, #2, and July 1974, Vol. 54, #7 were the sources of the consumer price indexes.

Shellfish and Finfish Industries

Oysters

Tropical Storm Agnes caused large oyster mortalities in the Chesapeake Bay and its tributaries during the summer of 1972. Resulting losses in current dollars to the harvesting sector was $13.8 million and to the processing sector $8.4 million. In order to determine the economic impact of

Agnes, for the years 1972 and 1973, it was necessary to estimate what landings and revenues would have been without Agnes. Estimation of losses for 1974 required estimates for both actual landings and revenues given the occurrence of Agnes and potential landings and revenues which would have been realized if Agnes had not affected the Bay. These are summarized in Table 4.

Table 4. Estimated current dollar loss in Maryland and Virginia oyster landings and value added in the oyster processing industry attributable to Tropical Storm Agnes.

YEAR	POUNDS LOST (lbs.)	DOLLAR LOSS IN LANDINGS MARYLAND	VIRGINIA	VALUE ADDED LOSS IN PROCESSING	TOTAL
1972	6,355,900	$1,602,000	$2,241,800	$3,178,000	$7,021,800
1973	4,935,800	0	2,220,800	2,467,900	4,688,700
1974	5,585,500	5,300,000	2,440,000	2,792,800	10,532,800

A major effect of Agnes on oyster production may not, however, be felt until the late 1970's or later and probably can never be accurately documented. The aftermath of Agnes created water conditions that virtually eliminated oyster spawn and set during 1972 in both Maryland and Virginia waters. While the short run reduction in oyster production that will occur in 1975 and to a lesser extent in 1976 represents a direct effect, a more serious long range effect can result from a semi-permanent reduction in the stock of oysters producing spawn and set. Failure to replenish the oyster stock needed to provide seed oysters could cause a much longer recovery period to reach some "normal" or "desired" level of production.

The decreased volume of oysters landed also had a fairly large impact on the oyster processing industry, which is located in the Bay region (Table 4). The normal markup by oyster processors is about 78 percent of the exvessel price. This suggested that the processors markup was about 50 cents per pound in 1971. Assuming that the processors markup remained at 50 cents per pound, the value added loss to Maryland and Virginia in 1972-73 was \$5.6 million bringing the total loss accruing to the harvesting and processing sectors, for the two years to \$11.7 million (Table 4). Estimated total losses for 1974 were projected to be \$10.5 million (Table 4).

Soft Clams

In the summer of 1972 the soft clam industry of Chesapeake Bay was centered in Maryland, there being essentially no active harvesting operations in Virginia waters at that time. Biologic surveys taken in Maryland indicated that market-sized soft shell clams suffered over 90% mortality and that about 95% of the surviving commercially harvestable soft shell clams were concentrated in less than 5,000 acres (Maryland State Department of Health and Mental Hygiene). This decimation of adult soft clams led the Maryland State Department of Natural Resources to impose a ban on clamming in September 1972. Attributing all the decrease in landings to Agnes resulted in estimates of 1972-73 losses at the fishing and processing levels of \$5,456,300 and \$2,334,000 respectively. Losses for 1974 were projected to be \$2,094,300 at the fishermen's level, and $1,457,900 at the processors' level. Total direct losses in current dollars attributable to Agnes were $11.3 million.

Hard Clams

Agnes produced a relatively minor economic impact on the hard clam industry in Virginia and none in Maryland. Hard clams survived the fresh waters of Agnes with one prominent exception. Clams that had been relocated from the James River to the York River and its tributaries in order to undergo a 3 week cleansing period suffered almost 50 percent mortality. Normally, minimal loss is observed in relocated clams, and since only relocated clams were affected, the combination of stress and low salinity levels were apparently responsible. Using data from the Virginia Marine Resources Commission it was estimated that 7,035 bushels of relocated clams were affected by Agnes producing a direct loss of $42,410.

Crabs and finfish

Revenues from the production of crabs and finfish indicate that Agnes did not significantly reduce catches in 1972 and 1973. The crab catch continued to conform to biologists' expectations and catches of menhaden, the most significant contributor to the dollar value of Virginia finfish, increased approximately one-third in 1972. Biologists' field samples indicate that both crabs and finfish remained in waters with salinity levels acceptable to their species and were therefore pushed out of the bay and its tributaries by the infusion of fresh water but returned as salinity levels returned to normal. Fishing was disrupted for periods ranging up to three weeks, but no estimates of the costs of these disruptions have been made. Agnes probably reduced the reproductive success of some fishes, most notably shad and river herring. The economic impact will not be felt until 1976 when the 1972 yearclass enters the fishery. The cost cannot be estimated at this time.

Economic Impact on Recreation Industries and Users

The recreation activities most predominant on the Chesapeake Bay historically have been fishing, hunting, crabbing, boating, swimming and sightseeing. Many of these activities were curtailed by Agnes. Boating and therefore fishing were made difficult by floating debris in many areas of the Bay. Beaches were closed because of potential or confirmed health hazard for varying periods of time. Sportcrabbing and sportfishing were less productive than normal. Businesses which served the recreationists - motels, restaurants, marinas, bait and boat sales places - lost revenue because of the Agnes-caused decrease in recreation activity. Losses totaled $7.5 million in the two states in those segments of the tourism and recreation industries for which a basis of estimating existed. This is considered a minimal estimate of the loss to the economy of the area inasmuch as no data base exists from which to estimate some losses. In the following discussion, losses in each state are discussed separately because the investigators had available to them different data bases and used somewhat different approaches.

MARYLAND

Motels

In order to measure the economic impact of Agnes on the Maryland motel industry, motels in all of the counties which touch on the Bay were surveyed. According to survey response, the total decrease in business which motel operators attribute to Agnes' effect on the Bay amcunted to around $181,000[1]. For some motels business decreased only during the immediate period of the storm, but for others, business was poor all summer.

Other Recreation Industries

There was no direct information on the impact of Agnes on the Maryland restaurant business. However, the motel survey found that 7,726 motel customer days were lost because of Agnes. Motel customers make heavy use of the restaurant industry. An A. D. Little study of tourism in Maryland in 1972 found that motel-staying boaters spend about 80% as much at eating and drinking places as at motels. This figure was applied to the motel loss to obtain an estimate of the loss to Bay area restaurants, or $145,000. This was considered a minimum estimate of losses because it only measures the loss of customers who stayed in motels. Potential restaurant customers who live in the area or make day trips to boat, fish or sightsee, were also discouraged from these activities because of Agnes and its aftermath.

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[1]From the sample it was estimated that 7,726 visitor days were lost. This was multiplied by a per person room rate of $9 and inflated by 2.6 to represent all motels.

The A. D. Little study also reported that a motel-staying recreationist would probably spend an additional $6 to $8 in the area, per day. Using the same method as above, at least $54,000 in gross revenue was lost to retain establishments, such as gas stations, because of Agnes. State parks also serve the recreationist. Four state parks along the Bay attributed to Agnes decreases in income amounting to $70,000.

Marinas

In 1972 there were approximately 320 marinas (places which charged for rental of 10 or more slips and moorings) along the Chesapeake Bay and its estuarine tributaries. Information on the impact of Agnes on marinas was derived from Economic Analysis in Maryland, The Boating Almanac, and a small telephone survey conducted in March 1974.

Had Agnes not occurred, the marina business would have grossed close to $9 million not including restaurant business. This figure was arrived at by updating the average revenue per marina in Economic Analysis of Marinas in Maryland by use of the average increase in slip rental price, in gas prices, and and in the consumer price index, and multiplying by the number of marinas operating on the Bay in 1972. Marina operators on average believed their loss of revenue was about 13% of their business, or a gross dollar loss of 1.1 million.

Impact on Recreation Users

The use of the Bay for swimming, fishing, boating, and other recreation activities affords utility to large members of recreators. The travel-cost method was used to estimate the value of the Bay to sport-fishermen. There have been extensive creel censuses of the Bay which provided information on how many anglers came from different distance zones in order to fish on the Chesapeake Bay in the summer. The total value to fishermen of their use of the upper Bay proper for the summer season, the area under the resource demand curve, was estimated to be approximately $1,378,000 in 1972.

After Agnes, portions of the Bay were closed to boating. Even when boating was allowed, it was more hazardous than normal because of floating debris. Pier fishing was also interrupted, due to inclement weather and lack of fish. In any case, pier fishing accounts for less than 1% of the angler days on the Bay proper. On average, fishing from boats was not possible for three weeks of usually prime fishing time. According to the 1962 Elser creel census, 16% of the season's angler-days would have occurred during this three week period. The value lost to fishing recreationists then was about $220,500. The loss estimated above was the value lost to fishermen only. Non-fishing boat-owners were similarly affected. National and state boat-owner surveys have found that only 40% of all boat owners use their boats for fishing. This indicates that there were 1.5 times as many non-fishing boat owners as fishing ones. Assuming that they use their boats for pleasure cruising or water skiing with the same frequency as fishermen, and their demand curve for the Bay was similar to that of the sport fishing boat owners, an additional $330,700 in recreational value was estimated to have been lost by non-fishing recreationists because of Agnes.

The closure of the upper part of the Bay to water contact sports, which lasted until August 12, 1972 caused a loss to large number of people. However, because of the lack of information, it was impossible to estimate the loss to recreationists who would have participated in water contact sports.

VIRGINIA

Tourism

While precise data were not available on tourism expenditures *per se*, the absolute dollar expenditures on three tourist-oriented industries were compared, by quarters, from 1970 through 1973 for counties and cities in Tidewater and Eastern Shore to determine the effect of Agnes. The data were obtained from the Department of Taxation, Taxable Sales Annual Reports and cover expenditures for "motels and hotels," "restaurants" and "sports and hobbies".

In order to determine the direct effects of Agnes on tourism, expected revenue was calculated for the spring quarter of 1972 for the three industry groups, and subtracted from the actual spring quarter revenue. Expected revenue was determined by a simple average of the revenue for the spring quarters of 1971 and 1973 and checked with the growth rate for 1970-73 for consistency. A check for inordinately large increases between 1972-73 during the summer quarter was made in order to ensure that the increase was not overly influenced by additions to facilities between 1972 and 1973.

The total direct loss in tourism revenues attributed to Agnes was estimated to be $3.5 million, with $2.4 million of that loss in the Norfolk and Virginia Beach areas. This was considered a conservative estimate since the assessment included only those industries primarily tourist oriented; i.e., purchases of all other goods and services by tourists, such as gasoline, groceries, theater admissions, etc., have not been included.

Sportfishing

The economic impact of Agnes fell also on the many business firms and individuals who derive part or all of their income from the very sizable sportfishing industry in Virginia.

There are really two separate sectors of the sportfishing industry, one of which might be called the "commercial" sportfishing industry, the other the "private" sportfishing industry. Of these, the commercial sector, which includes charter and head-boats, fishing piers, and boat rental businesses, is the more visible, and it did suffer some losses from Agnes. But much larger losses befell the "private" sector, which represents those many businesses that sell the variety of goods and services used by private boat owners in operating their own craft for their own enjoyment.

(1) Commercial sportfishing

The revenue losses accruing to charter and head-boat fishing because of Agnes were confined to the inshore boats, which are fairly few in number, usually lower in prices, and see less intensive normal utilization than the offshore boats. Charter and head-boat fishing involve large outlays by passengers, on the order of up to $165 per day for a six-passenger chartered boat and $8-20 per day per passenger for head-boats carrying as many as 40 passengers, and Virginia apparently has many such boats. Losses were minimized, however, because of the interplay of two factors: one, the impact on ocean (as contrasted with Bay) fishing from Agnes was virtually nil and, secondly, the large majority of Virginia boats either are exclusively for off-shore use or have the size, range and location that enable them to head offshore as an alternative to fishing in or around the Bay. The largest charter and head-boat fleets in Virginia are either already ocean-based, such as those at Wachapreague on the Eastern Shore or at Rudee Inlet in Virginia Beach, or have easy access to the ocean, such as those based in the Norfolk area from Willoughby Bay to Little Creek, and on the North shore of Virginia Beach in Lynnhaven Inlet.

Thus, to whatever extent charter and head-boat fishing revenues were affected by Agnes, losses were confined to the inshore boats, which are fairly few in number, usually lower priced, and see less intensive normal utilization than the off-shore boats. Estimates of even these losses are difficult to come by, because these boats are largely decentralized in location and do not use central booking services. However, a total loss to them within the $25,000-$50,000 range is estimated to have occurred, and the mid-point of that range

$37,500, is accepted as a reasonably accurate loss figure.

While charter boat fishing is by far the dominant fraction of the commercial sportfishing industry in Virginia and losses to it related to Agnes were not large, there are other elements of commercial sportfishing which, though much smaller in size, suffered proportionately more damages. In this regard, particularly, are the fishing pier and small-boat rental businesses.

There are nine commercial fishing piers in Virginia, only two of which extend into the ocean; the remaining seven are all located at the mouth of or inside the Bay. While precise damage figures to these seven are not available on an individual basis, our survey of pier owners and operators indicates that the average losses to the four larger piers in the lower Bay attributable to Agnes were approximately $15,000, representing more the continuing impact throughout the summer than the absence of business during the storm period. Losses to other piers totalled no more than $10,000. Thus, Agnes-related revenue losses to fishing pier operators are estimated at $70,000.

Another facet of this economic sector is small boat rentals. A survey of these small boats, salt water rental firms indicated that total losses to them from Agnes probably came to only $10,000.

Thus, the total Agnes-related losses to all elements of the commercial sportfishing industry in Virginia total approximately $117,500.

(2) Private Sportfishing

But as commercial sportfishing losses were small, the impact of the decrease in private sportfishing was not. The analysis indicated that losses in this sector were the product of two factors: the total number of boating days (average boats per day multiplied by the number of days affected) lost because of Agnes and the typical monetary outlay per boat day. About $1.78 million dollars were assumed not spent in the lower Bay area by private sportfishermen on gas, bait, food and beverages.

Other Impacts

Tropical Storm Agnes caused economic losses other than those relating to commercial and private sportfishing. Among the other losses are those that concern channel maintenance, debris removal, and boat and marine equipment damages.

However, of these, only the first looms large as an out-of-pocket loss. Reports for the U. S. Army Corps of Engineers, Norfolk District, indicated that thus far the flooding of 1972 in the tidewater estuaries of Chesapeake Bay has caused $695,000 in dredging expenses, above normal maintenance costs.

Extensive interviews support the opinion that debris removal was largely left to nature itself, or was done by marina and waterfront property owners and boaters themselves on a non-commercial basis. Furthermore, it also appeared that many boat damages were to the small boat owner and to a considerable extent were of small individual magnitude.

Many of these damages were hull scrapes and gouges that were repaired by the owners themselves.

In regard to damages to larger boats which tend to be more costly per incident, data provided by the United States Coast Guard Station in Norfolk indicated that there were Agnes-connected incidents of damage to five barges and one Navy vessel, also totaling an estimated $10,000 in damages. The reporting requirements for marine casualty damages specify at least a $1,500 damage level, and thus all losses above that amount presumably were reported.

Accordingly, the economic damages from Agnes relating to channel clearance, debris removal, and boat damages totaled $1.6 million in Chesapeake Bay and its tidal tributaries of which $715,000 was expended in Virginia and $900,000 in Maryland.[1]

Public Health Impacts

Prompt action by the State Health Departments in Maryland and Virginia in closing the waters of the Bay to shellfish harvesting for direct human consumption, undoubtedly prevented marketing of contaminated shellfish. The higher bacterial counts in the Virginia portion of the Bay appeared to be primarily associated with runoff from the initial rains. In Maryland, the bacterial levels were to a greater extent attributed to material entering with the flood waters. The overall public health impact of Agnes on Chesapeake Bay

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[1]The U. S. Army Corps of Engineers served as the major source of these data.

was minimal with the possible exception of economic dislocations caused by shellfish and water contact recreation closings.

Shellfish Closings

On 23 June 1972, the waters of Chesapeake Bay were closed for the taking of shellfish for direct consumption by the Maryland Department of Health and Mental Hygiene (MDH) and the Virginia Department of Health (VDH) in waters under their respective jurisdiction. On 10 July the MDH reopened the first of the areas closed due to Agnes on the Eastern Shore side of the Bay. By 1 August most of the Eastern Shore waters in Maryland were reopened.

In Virginia, the "Bay proper" below New Point Comfort was opened on 20 July. The York River was opened on 1 August followed by the James of 3 August and the Rappahannock on 9 August. By 5 October 1972 all remaining areas in Virginia closed due to Agnes had been reopened.

Reopenings in Maryland were complicated by a Maryland Department of Natural Resources (DNR) ban on all soft shell clam harvesting to protect remaining clam populations. On 18 September 1972 the Maryland DNR opened the oyster season.

Water Contact Closings

On 30 June 1972, the MDH closed the Maryland portion of the Bay to water contact recreation. No comparable closing was made for Virginia waters. Since the Potomac River to the Virginia shore is within Maryland jurisdiction, this closing did impact the water related recreation industry within these Virginia localities with shorelines abutting on the Potomac River.

On 7 July the ban was lifted for Baltimore, Ann Arundel and Calvert Counties. By 15 July the ban was lifted for all but the Maryland portion of the Susquehanna River, the upper Choptank River, the Patuxent River and the Potomac River above the Potomac River Bridge. On 28 July the ban was lifted on the remaining areas.

In the Virginia portions of Chesapeake Bay, water contact bans imposed by the Norfolk, Virginia Health Department and the U. S. Navy at beaches under their jurisdiction on 14 July and 19 July respectively were initially attributed in part to Agnes flood waters. Subsequent investigation, however, attributed these closings to a faulty sewer main in the Norfolk system.

Shellfish Contamination

Analysis of pesticide and heavy metal accumulation in shellfish indicate that there was no accumulation of these materials sufficient to cause a public health hazard.

Waterborne Pathogens

No evidence of increased incidence of infection by waterborne pathogens as a result of Agnes was found. Fifty-six percent fewer cases of infectious hepatitis were reported in June, July and August 1972 in Virginia than in the comparable period in 1971.

Miscellaneous Hazards

No incidents of injuries or health impairment due to hazardous substances entering the estuarine portions of the Bay region with flood waters were reported.